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DEVELOPMENT AND EVALUATION OF NEW CALIBRATION SITE, TYNDALL AFB, FOR CONTINUOUS FRICTION MEASUREMENT EQUIPMENT

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14. ABSTRACT

The Air Force Civil Engineering Center (AFCEC) has been measuring military runway pavement friction and texture conditions around the world for many years. In recent years, the friction measurements have been collected using seven GripTester (GT) trailers, and pavement texture measurements using the NASA grease sample method (ref. 1). The main purpose of developing a calibration site at Tyndall AFB, Florida, is to provide an efficient way to maintain the seven GTs within calibration limits and to provide a range of test surface textures for measurement with different, more efficient equipment than the NASA grease sample method. Hence the scope of this contract project between USAF AFCEC and Chemtek/AeroGroup involved: 1. obtaining six different calibration test surfaces; 2. collecting data using seven USAF GTs, a Dynamic Friction Tester (DFT), a CT meter and a HTD meter; 3. correlating these friction and texture measurement; and 4. determining the International Friction Index (IFI) values. The work of achieving the six calibration test surfaces was completed in June 2015 using the Skidabrader machine. Five of the USAF GTs were evaluated together with the HTD meter in late June, early July 2015. In August 2015, the DFT and the CT meter collected friction and texture data on the six test surfaces. In October 2015, data was collected on the six calibration surfaces with the other two USAF GTs. The following sections of this report will describe the calibration site surfaces, the test equipment and procedures used, the data collection, analysis and reduction, determination of the IFI values, the data correlation with several conclusions and recommendations are given as well as a list of appropriate references.

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Development and Evaluation of New Calibration Site

Tyndall AFB for Continuous Friction Measurement Equipment

February 2016

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Under

Chemtek/AeroGroup/USAF Tyndall AFB Contract FA8051-14-P-0026

Development and Evaluation of New Calibration Site at Tyndall AFB for Continuous Friction Measurement Equipment

Acknowledgements

The primary facilitators for developing this new calibration site for Continuous Friction Measurement Equipment (CFME) is the USAF Civil Engineering Center (AFCEC) at Tyndall AFB, Florida, and the prime contractor was Chemtek/AeroGroup. The Skidabrader Company supported most of the work to achieve calibration test surface texture variation. This work resulted in two lanes, left (L) and right (R), each lane with three different textures plus the original runway pavement texture (surface L0). Seven GripTesters were provided and operated by one of the Tyndall AFB skid resistance teams. Chemtek/AeroGroup contacted the National Center for Asphalt Technology (NCAT) at Auburn University, AL for use and operation of a Dynamic Friction Tester (DFT) and a Circular Texture meter (CT meter). A HydroTimer drainage meter (HTD meter) was provided by one of the data analysis consultants, and a second consultant was contacted to support the data analysis, reduction and correlation of calculations needed to determine the USAF required International Friction Index (IFI) values. Hence, four authors prepared the report.

Introduction

The Air Force Civil Engineering Center (AFCEC) has been measuring military runway pavement friction and texture conditions around the world for many years. In recent years, the friction measurements have been collected using seven GripTester (GT) trailers, and pavement texture measurements using the NASA grease sample method (ref. 1). The main purpose of developing a calibration site at Tyndall AFB, Florida, is to provide an efficient way to maintain the seven GTs within calibration limits and to provide a range of test surface textures for measurement with different, more efficient equipment than the NASA grease sample method.

Hence the scope of this contract project between USAF AFCEC and Chemtek/AeroGroup involved: 1. obtaining six different calibration test surfaces; 2. collecting data using seven USAF GTs, a Dynamic Friction Tester (DFT), a CT meter and a HTD meter; 3. correlating these friction and texture measurement; and 4. determining the International Friction Index (IFI) values. The work of achieving the six calibration test surfaces was completed in June 2015 using the Skidabrader machine shown in Figure 1. Five of the USAF GTs were evaluated together with the HTD meter in late June, early July 2015. In August 2015, the DFT and the CT meter collected friction and texture data on the six test surfaces. In October 2015, data was collected on the six calibration surfaces with the other two USAF GTs. The following sections of this report will describe the calibration site surfaces, the test equipment and procedures used, the data collection, analysis and reduction, determination of the IFI values, the data correlation with several conclusions and recommendations are given as well as a list of appropriate references.

Calibration Test Site

Figure 2 provides a schematic diagram of the calibration test site concrete surface arrangement with three surfaces in the left lane, L1, L2 and L3, and three surfaces in the right lane, R1, R2 and R3. Each concrete test surface was 200 feet long and 8 feet wide with a painted 25 foot long separation strip between test surfaces to help in separating data collected from each test surface. All test runs with the seven USAF GTs were made in the same direction, in both lanes with the same tow vehicle, test measuring tire and water distribution system. Measurements with the DFT, CT meter and HTD meter were taken at random locations on each of the six test surfaces.

Close-up photographs of each of these test surfaces are provided in Figure 3, a-f. Except for test surface R3, the other five test surfaces were obtained using the Skidabrader high impact shot pellet machine to vary the texture of each 200 foot test surface. The highest texture surface, L2, was obtained using the Skidabrader and 40,000 psi High Pressure Water. The very smooth, lowest texture surface R3 was prepared by applying several coatings of Self Leveling Cement to this 200 foot test surface to substantially reduce the pavement texture.

Test Equipment

a. USAF GripTester (GT) trailers

The GT trailer is a three-wheel device (Ref. 2 -4) with the smooth tread measuring tire operating at 17.5% slip due to a chain drive gear wheel connection between the two drive

wheels and the test tire. Figure 4 shows the GT trailer. Figure 5 shows a photograph of the GT's underside. Figure 6 shows front and rear schematic views of the GT. A water tank in the tow vehicle and distributing hose and nozzle mounted in front of the test tire can deliver 1 mm water depth at any speed. The drag and vertical loads together with forward velocity are continuously measured and recorded on a laptop computer. Normal runway friction measurement speed is 40 mph but replicate test runs at 60 mph were also performed. Five of these GTs were tested in June 2015 and the other two GTs in October 2015.

b. Dynamic Friction Tester (DFT)

Figure 7 shows a top view of the DFT friction measuring device and Figure 8 shows the DFT underside with rubber pads attached to three motor-driven rotating arms (Ref. 5). Once the DFT motor is turned on, the speed is increased to the desired speed, 1 mm water depth is turned on, and then the rotating arms are lowered to the pavement surface. Rotational speed is reduced to a stop in proportion to the friction developed. This is a portable, stationary device and hence, nine measurements were taken randomly on each of six test surfaces, plus a control surface. Average test surface DFT friction values were then calculated for correlation.

c. Circular Texture meter (CT meter)

Figure 9 shows the CT meter which uses a laser mounted on a motor, rotating arms of similar length as used on the DFT friction measurement device. The pavement profile measured by the laser is recorded and translated into pavement texture values (Ref. 6). This too is a portable stationary device and hence, fifteen measurements were randomly taken on three different

concrete slabs in each of the six test surfaces, plus a control surface. Overall average texture values were determined for each test surface.

d. HydroTimer drainage meter (HTD meter)

Figure 10 shows the HTD meter, formerly referred to as an outflow meter (Ref. 7). The cylindrical tube has an electrical timer/clock installed to record the time required for a fixed amount of water to escape through a hole at the bottom of the tube surrounded by a rubber donut. The HTD meter has a base rubber sealing ring. A measured volume of water is released in the center of the sealing ring while an electronic timer indicates how long it takes the water to pass through texture voids in the pavement under the seal. Smoother pavement texture increases the time required for the water to escape.

Data Collection

Table I contains the measured and average friction values obtained by each of the seven USAF GTs, by model number and date collected. Three replicate runs at 40 mph and 60 mph were conducted on each test surface. This data was collected in June and October 2015.

Table II contains the HTD meter data collected on each calibration test surface at three randomly selected locations. The three 6000 sec. measurements obtained on the very smooth R3 test surfaces were estimated time intervals calculated from 10 minute values of water drained from tube. With L2 having the lowest average time (2.97 sec.) and R3 having the highest average time (6000 sec.), L2 time indicates the greatest texture and R3 the lowest texture. This data was collected on June 30 and July 1, 2015.

Table III contains the DFT data collected on each of the six test surfaces at 20, 40 and 60 km/h from nine test runs at each speed. An overall average for each test surface and each test speed is also given. This data was collected on August 24, 2015.

Table IV contains the CT meter texture measurements collected on all six test surfaces and a control surface at fifteen random locations on each test surface. The overall average texture value for each test surface is also provided. In addition to the mean profile depth (MPD) values, the average percent dropout value is given together with the average root mean square (RMS). This data was collected at random locations on each test surface under dry conditions on August 24, 2015.

Determination of IFI Values

PIARC sponsored an international friction harmonization study in 1992, in which representatives from 16 countries participated. The experiment was conducted at 54 sites across the U.S. and Europe and included 51 different measurement systems. Various types of friction testing equipment were evaluated, including locked-wheel, fixed-slip, ABS, variable-slip, side-force, pendulum, and some prototype devices. Surface texture was measured by means of the sand patch, laser profilometers (using the triangulation method), an optical system (using the light sectioning method), and outflow meters.

One of the main results of the PIARC experiment was the development of the International Friction Index (IFI). The IFI standardized how the dependency of friction on the tire sliding speed is reported. As a measure of how strongly friction depends on the relative sliding speed of an

automotive tire, the gradient of the friction values measured below and above 37 mi/hr (60 km/hr) is reported as the value of an exponential model for the IFI index. This gradient is named the Speed Number (*SP*), and is reported in the range 0.6 to 310 mi/hr (1 to 500 km/hr).

The PIARC experiment strongly confirmed that *SP* is a measure of the macro-texture influence on surface friction. Macro-texture is recognized as a major contributor to friction safety characteristics for several reasons. The most well known reason is the hydraulic drainage capability that macro-texture has for wet pavements during or immediately after a rainfall. This capability will also minimize the risk for hydroplaning. Another reason is that the wear or polishing of macro-texture can be interpreted from *SP* as it changes value over time for a section of road.

A pronounced peak shape or a steep negative slope of the friction–slip speed curve is considered dangerous. The normal driver will experience an unexpected loss in braking power when the brake pedal is pushed to its maximum, and the braking power is not at its maximum. A smallest possible negative slope or even a flat shape of the friction–slip speed curve is therefore desired and obtained with proper macro-texture.

The IFI is composed of two numbers—*F(60)* and *SP*—and the designation and reporting of this index is *IFI(F(60)*, *Sp*). The IFI is based on a mathematical model (called the PIARC Friction Model) of the friction coefficient as a function of slip speed and macro-texture. The IFI speed

number and friction number are computed using the following equations (expressed in metric form, as outlined in ASTM E 1960):

$$SP = a + b \times TX \qquad \text{Eq. 1}$$

where: *SP* = IFI speed number.
a, *b* = Calibration constants dependent on the method used to measure macrotexture.
For *MPD* (ASTM E 1845), a = 14.2 and b = 89.7
TX = Macro-texture (*MPD* or *MTD*) measurement, mm.

$$FR(60) = FR(S) \times e^{((S-60)/Sp)} \qquad \textit{Eq. 2}$$

where: *FR(60)* = Adjusted value of friction measurement *FR(S)* at a slip speed of *S* to a slip speed of 60 km/hr.
FR(S) = Friction value at selected slip speed *S*.
S = Selected slip speed, km/hr.

$$F(60) = A + B \times FR(60) + C \times TX \qquad \text{Eq. 3}$$

where: *F(60)* = IFI friction number obtained from the correlation of equation 3.
A, *B* = Calibration constants dependent on friction measuring device.
C = Calibration constant required for measurements using ribbed tire.

From previous calibrations, the IFI values of a site can be obtained from the CTmeter MPD and the DFtester DFT20.. See appendix A for details. Table V gives the IFI values for the Tyndall AFB calibration sites.

Table V IFI values for the Tyndall AFB calibration sites

Site	Sp	FG60
L1	59.65	0.252
L2	129.61	0.376
L3	68.02	0.289
R1	47.99	0.234
R2	61.44	0.264
R3	22.57	0.114

Table VI gives the A and B constants for each GripTester and C is zero since the GripTester uses a blank tire.

$$F(60) = 0.117 + 0.458 \text{ x GT300 40 x } e^{-48.992/Sp} \qquad \text{Eq. 4}$$

Table VI A and B constants for each GripTester

GripTester	A	B
GT300 40mph	0.1173	0.4580
GT448 40mph	0.1249	0.4427
GT225 40mph	0.1379	0.4578
GT557 40mph	0.1274	0.4392
GT343 40mph	0.1232	0.4081
GT344 40mph	0.1251	0.3868
GT226 40mph	0.1251	0.4040

Since the GripTester has a slip ratio of 17.5%, 40mph is a slip speed (S) of 11.008 km/h and (S-60) is -48.992. Then for example, GT300 40mph would use:

See appendix B for an example calculation

Data Reduction and Analysis

Average friction and texture data was used in determining the level of these parameters on each of the six calibration surfaces. The seven USAF GT data are plotted at 40 and 60 mph in

Figure 11 for each test surface. Based on these two plots, GT 448 was selected as the "golden" GT since it provided the most mean values of all seven GTs at both 40 and 60 mph. These average GT friction values are in agreement with the two texture measuring devices in that L2 produces the highest value and R3 the lowest value.

The DFT friction values are plotted in Figure 12 at 20, 40 and 60 km/h. Similar to the USAF GTs, as speed increases, the wet friction performance decreases.

The CT Meter and HTD meter average values are plotted in Figure 13 for each test surface. This data also indicates L2 has the highest texture and lowest time and R3 the lowest texture and longest time.

A correlation between the golden GT448 and the DFT at two speeds for each test surface are plotted in Figure 14. Again the data indicates L2 surface has highest texture and R3 the lowest.

Figure 15 shows a correlation plot between the golden GT448 and the CT Meter values for each test surface.

Figure 16 is a correlation plot between the golden GT448 and HTD Meter for each test surface.

Using GT448 as the "Gold" tester, all other GripTesters were the correlated to it using a linear correlation;

$$GT448 = \alpha + \beta * GTXXX \qquad \text{eq.5}$$

Other types of correlations were tried , but, a linear correlation gave the best results. Table VII gives the values of α aand β for each GripTester. Appendix C gives an example for GT225. Table

Table VII α aand β for each GripTester

	α	β
GT300 40mph	0.1173	0.4580
GT448 40mph	0.1249	0.4427
GT225 40mph	0.1379	0.4578
GT557 40mph	0.1274	0.4392
GT343 40mph	0.1232	0.4081
GT344 40mph	0.1251	0.3868
GT226 40mph	0.1251	0.4040

Conclusions and Recommendation

The data analysis indicates that the seven GripTesters are within the allowable ASTM friction limits of +/- 0.03 friction coefficient measured by the golden 448 GripTester. This new CFME calibration site is considered suitable for future calibration tests of any CFME devices. The measured friction and texture ranges are acceptable for good and accurate equipment calibration.

It is recommended that GT calibration testing be performed annually at this calibration test site. Once all the GT's collect their data, the IFI constants should be determined for each GT. The one with the best standard deviation would be selected as the golden GT and then the other GT's would be correlated to it. Appendix A explaines how to get IFI values for each site, Appendix B explains how to get IFI constant values from GT measurements and Appendix C shows how to correlate each GT to the golden one.

References

1. Anon: "Measurement, Construction and Maintenance of Skid-Resistant Airport Pavement Surfaces". Federal Aviation Administration Advisory Circular No. 150/5320-12C, March 18, 1997.
2. Anon., 2015. Annual Book of American Society for Testing and Materials Standards. Section four – Construction, Volume 04.03, Road and Paving Materials; Vehicle-Pavement Systems. ASTM International; West Conshohocken, PA, USA.
3. Anon: E2883, Standard Guide for the Evaluation and Calibration of Continuous Friction Measurement Equipment (CFME).
4. Anon: E2340/E2340M – 11, Standard Test Method for Measuring the Skid Resistance of Pavements and Other Trafficked Surfaces Using a Continuous Reading, Fixed-Slip Technique.
5. Anon: E2669, Standard Practice for Correlations of Mu Values of Continuous Friction Measurement Equipment to Determine Maintenance Levels for Use at Airports.
6. Anon: E1911 – 09a, Standard Test Method for Measuring Paved Surface Frictional Properties Using the Dynamic Friction Tester.
7. Anon: E2157 – 09, Standard Test Method for Measuring Pavement Macrotexture Properties Using the Circular Track Meter.
8. Anon: E2360/E2380M -15, Standard Test Method for Measuring Pavement Texture Drainage Using an Outflow Meter.
9. Anon: E1960 – 07 (Reapproved 2011), Standard Practice for Calculating tthe

International Friction Index (IFI) of a Pavement Surface.

10 Yager, T.J. and Buhlmann, F. : Macro-texture and Drainage Measurements on a Variety of Concrete and Asphalt Surfaces. Pavement Surface Characteristics and Materials, C.M.Hayden,ed.,ASTM Spec. Tech. Publ. 763, 1982.

11. Wambold, J.C., Antel, C.E., Henry, J.J., and Rado, Z., 1995. International PIARC Experiment to Compare and Harmonize Texture and Skid Resistance Measurements". Final Report, World Road Association (PIARC), Paris, France.

12. Wambold, J.C. and Henry, J.J., 2002. NASA Wallops Tire/Runway Friction Workshops 1993 -2002. Transport Canada report TP 14190E, Montreal, Canada.

13. Wambold, James C., Henry, J.J., Yager, Thomas J., and Boccanfuso, Angelo: 2004 International Runway Friction Index (IRFI) Versus Aircraft Braking Coefficient (Mu)

Appendix A Calculation of IFI Values

From the average values measured with the CTmeter of MPD and DFT20 from the DFtester, IFI values for the sites are obtained from:

$$Sp = 14.2 + 89.7 * MPD$$

And $$FG60 = 0.0811 + 0.732*DFT20*e^{-40/Sp}$$

Fro example, MPD was 0.507 and DFT20 was 0.456 for site L1. Yhus, Sp and FG60 are:

$$Sp = 14.2 + 89.7 * 0.507 = 59.63 \text{ Km/h}$$

$$FG60 = 0.0811 + 0.732 * 0.456 * e^{-40/59.63} = 0.252$$

Simiarly from the data, the following is calculated:

Site	MPD	DFT20	Sp	FG60
L1	0.506667	0.455667	14.20	0.081
L2	1.286667	0.548667	14.20	0.081
L3	0.6	0.512333	14.20	0.081
R1	0.376667	0.481	14.20	0.081
R2	0.526667	0.48	14.20	0.081
R3	0.093333	0.266667	14.20	0.081

Appendix B Sample Calculation of IFI for GT448

After making several runs at 40 mph with the GT448, the average for each site is calculated as GT448 40mph. In addition the MPD should be used to calculate the speed gradient Sp.

$$Sp = 14.2 + 89.7 * MPD$$

Where: Sp is the speed gradient in km/h
MPD is he Mean Profile Depth in mm

Then GT448 40mph data is used with Sp to move the measurement slip (S) to a slip of 60 km/h, we will call this GT448 R60. Since the GT448 has a slip of 17.5%, S is 64 km/n (40mph) times 0.175 or 11.008 km/h. Thus, S-60 is 11.008 minus 60 which is -48.992. From the IFI tables A and B for GT448 are A=0.1247 and B=0.4427. Thus, from:

$$GTxxxR60 = GTxxx40mph * e^{-48.992/Sp}$$

And $$GTxxxF60 = A + B * GTxxxR60$$

The GT448 40mph data is calculated as follows:

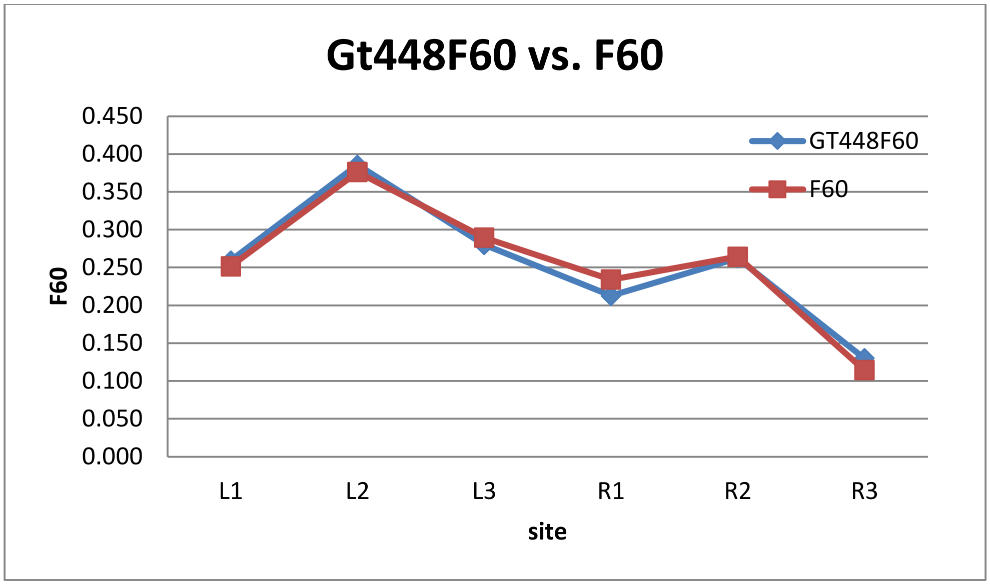
$$GT448R60 = GT448\ 40mph * e^{-48.992/Sp}$$

And $$GT448F60 = 0.1247 + 0.4427 * e^{-48.992/Sp}$$

This gives the values in the following table.

Surface/ Section>	GT448 40mph	Sp	GT448 R60	GT448 F60
L1	0.690	59.65	0.303	0.259
L2	0.860	129.61	0.589	0.386
L3	0.720	68.02	0.350	0.280
R1	0.550	47.99	0.198	0.213
R2	0.690	61.44	0.311	0.262
R3	0.100	22.57	0.011	0.130

Below is a figure showing the GT448F60 plotted along with the golden F60 for each site.


Gt448F60 vs. F60
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
F60
GT448F60
F60
L1
L2
L3
R1
R2
R3
site

Appendix C GT225cal

GT225 was calibrated to GT448, where GT448 is used as the “Golden” GripTester. Thus, all measurements with the GT225 should be revised as follows to obtain the calibrated value:

GTXXXcal 40mph = a + b*GTXXX 40mph

Where: GTXXXcal 40mph is the calibrated value
a and b are the calibration constants found in Table ?
GTXXX 40mph is the measured GT number

Or for example GT225 40mph would be:

GT225cal 40mph = -0.00714 + 1.080721 * GT225 40mph

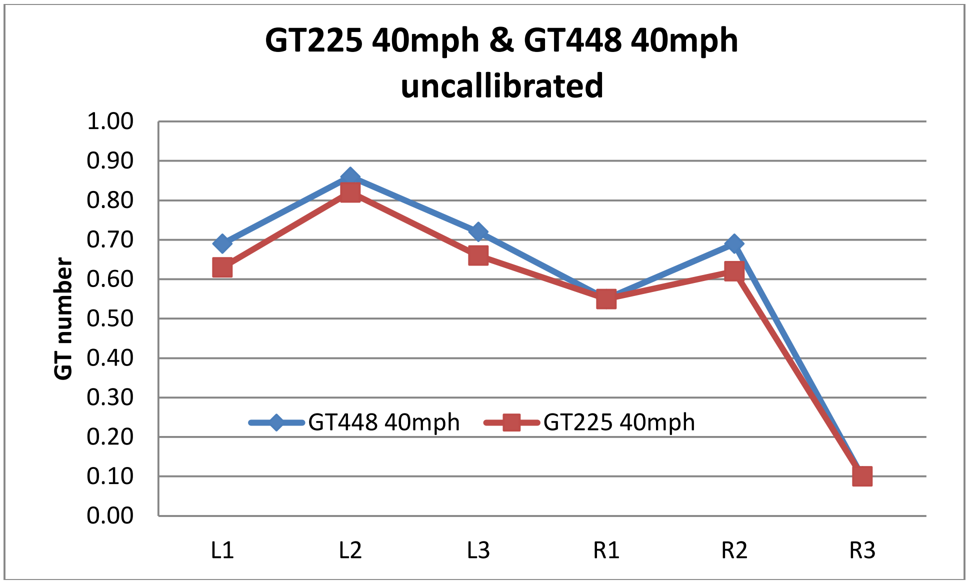
Thus, taking the GT225 40mph data:

Surface/Section>	L1	L2	L3	R1	R2	R3
GT225 40mph	0.63	0.82	0.66	0.55	0.62	0.10

And applying the calibration gives the following calibrated values, as compared to the measured values of the golden GT448 40mph.:

Surface/Section>	L1	L2	L3	R1	R2	R3
GT448 40mph	0.69	0.86	0.72	0.55	0.69	0.10
GT225cal 40mph	0.67	0.88	0.71	0.59	0.66	0.10

Below is first a figure comparing GT225 40mph measurements with GT448 40mph measurements. The second figure shows the comparison with the calibration of GT225 applied.


GT225 40mph & GT448 40mph
uncallibrated
GT number
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
GT448 40mph
GT225 40mph
L1
L2
L3
R1
R2
R3

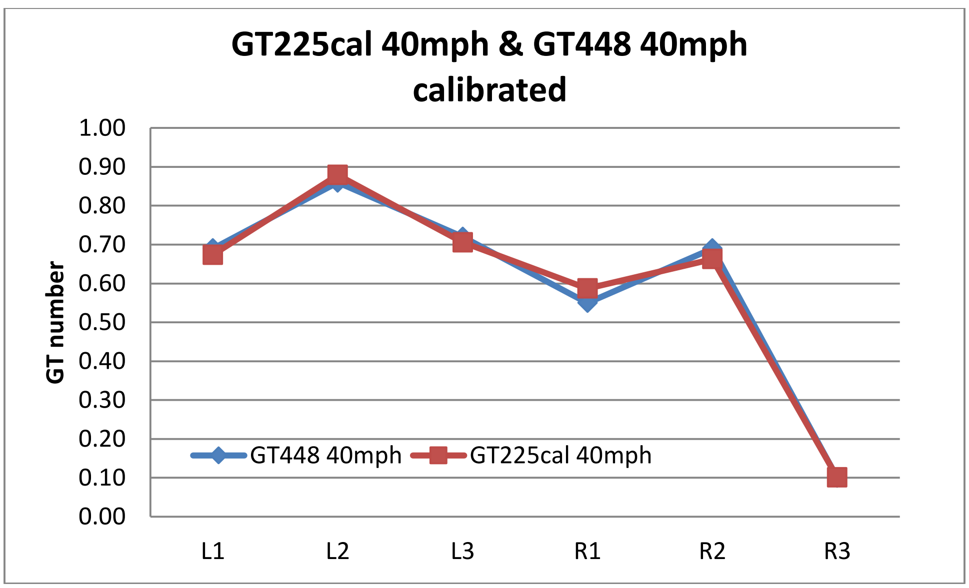

GT225cal 40mph & GT448 40mph
calibrated
GT number
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
GT448 40mph
GT225cal 40mph
L1
L2
L3
R1
R2
R3

Table I – USAF Griptester friction data

Time	GT 344			
		Section1	Section2	Section3
	L40			
13:21	Run 1	0.78	1.00	0.82
13:27	Run 2	0.77	1.00	0.82
13:32	Run 3	0.74	1.00	0.80
	R40			
13:24	Run 1	0.68	0.75	0.16
13:30	Run 2	0.67	0.75	0.15
13:34	Run 3	0.67	0.75	0.16
	L60			
13:36	Run 1	0.61	0.94	0.68
13:44	Run 2	0.61	0.92	0.67
13:48	Run 3	0.62	0.91	0.67
	R60			
13:42	Run 1	0.54	0.62	0.11
13:46	Run 2	0.47	0.63	0.11
13:50	Run 3	0.46	0.59	0.09

30-Jun

Time	GT 226			
		Section1	Section2	Section3
	L40			
14:26	Run 1	0.69	0.95	0.76
14:31	Run 2	0.74	0.96	0.78
14:35	Run 3	0.77	0.96	0.78
	R40			
14:29	Run 1	0.61	0.70	0.14
14:33	Run 2	0.64	0.73	0.14
14:37	Run 3	0.69	0.74	0.13
	L60			
14:39	Run 1	0.65	0.86	0.66
14:43	Run 2	0.59	0.92	0.69
14:47	Run 3	0.55	0.64	0.86
	R60			
14:41	Run 1	0.49	0.58	0.14
14:46	Run 2	0.50	0.58	0.14
14:49	Run 3	0.50	0.59	0.13

30-Jun

Time	GT 225			
		Section1	Section2	Section3
	L40			
16:33	Run 1	0.61	0.80	0.65
16:37	Run 2	0.65	0.82	0.66
16:41	Run 3	0.64	0.84	0.67
	R40			
16:35	Run 1	0.53	0.63	0.10
16:39	Run 2	0.60	0.63	0.10
16:45	Run 3	0.53	0.61	0.10
	L60			
16:47	Run 1	0.50	0.75	0.54
16:55	Run 2	0.53	0.75	0.55
17:01	Run 3	0.53	0.76	0.54
	R60			
16:49	Run 1	0.40	0.50	0.10
16:58	Run 2	0.40	0.49	0.10
17:03	Run 3	0.38	0.50	0.10

30-Jun

Table 1 – Continued

Time	GT 557			
		Section1	Section2	Section3
	L40			
8:58	Run 1	0.59	0.84	0.66
9:16	Run 2	0.69	0.90	0.75
9:26	Run 3	0.69	0.88	0.72
	R40			
9:14	Run 1	0.62	0.66	0.10
9:20	Run 2	0.54	0.64	0.10
9:28	Run 3	0.58	0.63	0.09
	L60			
9:30	Run 1	0.57	0.81	0.57
9:35	Run 2	0.53	0.82	0.55
9:41	Run 3	0.58	0.85	0.62
	R60			
9:33	Run 1	0.40	0.53	0.09
9:39	Run 2	0.39	0.52	0.09
9:45	Run 3	0.37	0.51	0.08

30-Jun

Time	GT 343			
		Section1	Section2	Section3
	L40			
10:53	Run 1	0.76	0.92	0.77
11:03	Run 2	0.73	0.95	0.77
11:08	Run 3	0.76	0.98	0.80
	R40			
11:01	Run 1	0.65	0.72	0.16
11:05	Run 2	0.65	0.72	0.15
11:18	Run 3	0.65	0.72	0.16
	L60			
11:20	Run 1	0.62	0.87	0.65
11:28	Run 2	0.61	0.91	0.68
11:34	Run 3	0.65	0.90	0.67
	R60			
11:24	Run 1	0.51	0.62	0.10
11:31	Run 2	0.49	0.62	0.10
11:39	Run 3	0.52	0.63	0.10

30-Jun

Table I – Concluded

GT 300			
	Section1	Section2	Section3
L40			
Run 1	Invalid Run		
Run 2	0.70	0.83	0.74
Run 3	0.71	0.84	0.75
R40			
Run 1	0.56	0.71	0.14
Run 2	0.56	0.71	0.14
Run 3	0.61	0.73	0.17
L60			
Run 1	0.68	0.82	0.70
Run 2	0.59	0.79	0.65
Run 3	0.60	0.79	0.65
R60			
Run 1	0.47	0.59	0.15
Run 2	0.43	0.56	0.15
Run 3	0.50	0.70	0.16

14-Oct

GT 448			
	Section1	Section2	Section3
L40			
Run 1	0.68	0.87	0.73
Run 2	0.70	0.85	0.71
Run 3	0.70	0.85	0.73
R40			
Run 1	0.59	0.69	0.10
Run 2	0.54	0.69	0.09
Run 3	0.53	0.69	0.10
L60			
Run 1	0.56	0.77	0.60
Run 2	0.56	0.80	0.63
Run 3	0.53	0.78	0.61
R60			
Run 1	0.42	0.56	0.10
Run 2	0.41	0.55	0.10
Run 3	0.38	0.55	0.11

14-Oct

	GT 225			
Time		Section1	Section2	Section3
	L40			
14:33	Run 1	0.71	0.89	0.74
14:39	Run 2	0.69	0.88	0.74
14:48	Run 3	0.66	0.86	0.72
14:53	Run 4	0.64	0.86	0.71
15:18	Run 5	0.67	0.87	0.72
	R40			
14:37	Run 1	0.65	0.68	0.16
14:45	Run 2	0.59	0.66	0.14
14:50	Run 3	0.60	0.65	0.13
14:56	Run 4	0.54	0.64	0.12
15:21	Run 5	0.60	0.67	0.13
	L60			
15:38	Run 1	0.56	0.85	0.61
15:48	Run 2	0.57	0.81	0.59
15:58	Run 3	0.57	0.81	0.61
	R60			
15:43	Run 1	0.46	0.56	0.09
15:53	Run 2	0.46	0.57	0.10
16:01	Run 3	0.47	0.56	0.10

29-Jun

Table II – Dynamic Friction Tester Data

Sample	km/h	Slab 3* Run 1	Slab 3* Run 2	Slab 3* Run 3	Slab 3* Avg	Slab 7* Run 1	Slab 7* Run 2	Slab 7* Run 3	Slab 7* Avg	Slab 10* Run 1	Slab 10* Run 2	Slab 10* Run 3	Slab 10* Avg	Section Average	km/h
Control	20	0.460	0.410	0.400	0.423	0.390	0.450	0.400	0.413	0.420	0.410	0.460	0.430	0.422	20
	40	0.410	0.350	0.330	0.363	0.340	0.400	0.340	0.360	0.380	0.340	0.380	0.367	0.363	40
	60	0.310	0.240	0.220	0.257	0.250	0.300	0.240	0.263	0.290	0.220	0.240	0.250	0.257	60
L1	20	0.440	0.550	0.440	0.477	0.410	0.490	0.420	0.440	0.430	0.490	0.430	0.450	0.456	20
	40	0.350	0.480	0.350	0.393	0.330	0.420	0.340	0.363	0.350	0.390	0.350	0.363	0.373	40
	60	0.240	0.340	0.210	0.263	0.210	0.300	0.210	0.240	0.240	0.230	0.250	0.240	0.248	60
L2	20	0.620	0.550	0.550	0.573	0.540	0.570	0.520	0.543	0.520	0.530	0.540	0.530	0.549	20
	40	0.570	0.510	0.520	0.533	0.480	0.510	0.460	0.483	0.460	0.460	0.470	0.463	0.493	40
	60	0.410	0.360	0.380	0.383	0.330	0.360	0.330	0.340	0.330	0.330	0.330	0.330	0.351	60
L3	20	0.580	0.610	0.550	0.580	0.570	0.530	0.430	0.510	0.510	0.440	0.480	0.477	0.522	20
	40	0.490	0.560	0.430	0.493	0.510	0.470	0.340	0.440	0.450	0.340	0.380	0.390	0.441	40
	60	0.350	0.430	0.290	0.357	0.380	0.330	0.220	0.310	0.310	0.210	0.240	0.253	0.307	60
R1	20	0.530	0.500	0.450	0.493	0.510	0.480	0.460	0.483	0.490	0.460	0.450	0.467	0.481	20
	40	0.430	0.400	0.360	0.397	0.400	0.390	0.370	0.387	0.380	0.360	0.350	0.363	0.382	40
	60	0.310	0.260	0.240	0.270	0.270	0.260	0.250	0.260	0.250	0.230	0.230	0.237	0.256	60
R2	20	0.520	0.470	0.450	0.480	0.510	0.500	0.470	0.493	0.490	0.450	0.460	0.467	0.480	20
	40	0.430	0.380	0.360	0.390	0.420	0.420	0.380	0.407	0.410	0.360	0.380	0.383	0.393	40
	60	0.280	0.250	0.210	0.247	0.270	0.290	0.250	0.270	0.260	0.230	0.240	0.243	0.253	60
R3	20	0.230	0.270	0.230	0.243	0.280	0.280	0.240	0.267	0.290	0.310	0.270	0.290	0.267	20
	40	0.170	0.230	0.200	0.200	0.210	0.180	0.140	0.177	0.230	0.220	0.190	0.213	0.197	40
	60	0.160	0.160	0.170	0.163	0.150	0.110	0.070	0.110	0.190	0.160	0.120	0.157	0.143	60

The Control sections were the last 3 slabs on the left before the beginning of the transition before section L1.

Table III – Circular Texture Meter Data

		Slab 3* Measurement #						Slab 7* Measurement #						Slab 10* Measurement #						Overall MPD
		1	2	3	4	5	Avg	1	2	3	4	5	Avg	1	2	3	4	5	Avg	
Control	Mean Profile Depth (Avg)	0.60	0.75	0.56	0.63	0.56	0.62	0.58	0.76	0.68	0.63	0.70	0.67	0.64	0.64	0.57	0.56	0.56	0.59	0.63
	% Dropouts (Avg)	4	3	2	3	3	3	3	3	3	3	4	3	3	3	3	4	3	3	
	RMS (Avg)	0.38	0.86	0.32	0.51	0.32	0.48	0.29	0.60	0.34	0.29	0.91	0.49	0.36	0.65	0.31	0.33	0.32	0.39	
L1	Mean Profile Depth (Avg)	0.43	0.43	0.44	0.45	0.44	0.44	0.50	0.48	0.50	0.50	0.50	0.50	0.56	0.56	0.59	0.59	0.58	0.58	0.52
	% Dropouts (Avg)	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	
	RMS (Avg)	0.23	0.22	0.22	0.22	0.22	0.22	0.25	0.25	0.25	0.26	0.26	0.25	0.32	0.31	0.32	0.32	0.32	0.32	
L2	Mean Profile Depth (Avg)	1.25	1.26	1.26	1.27	1.25	1.26	1.52	1.49	1.51	1.49	1.49	1.50	1.31	1.30	1.30	1.30	1.29	1.30	1.35
	% Dropouts (Avg)	1	1	1	1	1	1	2	1	2	2	2	2	1	1	2	1	1	1	
	RMS (Avg)	0.79	0.80	0.80	0.81	0.81	0.80	0.81	0.81	1.06	0.81	0.81	0.86	0.73	0.73	0.72	0.72	0.72	0.72	
L3	Mean Profile Depth (Avg)	0.58	0.57	0.59	0.57	0.59	0.58	0.64	0.65	0.64	0.64	0.64	0.64	0.58	0.58	0.58	0.58	0.57	0.58	0.60
	% Dropouts (Avg)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	
	RMS (Avg)	0.31	0.31	0.41	0.31	0.31	0.33	0.34	0.34	0.34	0.34	0.34	0.34	0.33	0.32	0.32	0.32	0.32	0.32	
R1	Mean Profile Depth (Avg)	0.38	0.38	0.38	0.39	0.39	0.38	0.35	0.35	0.35	0.36	0.36	0.35	0.39	0.39	0.40	0.40	0.40	0.40	0.38
	% Dropouts (Avg)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	RMS (Avg)	0.19	0.19	0.19	0.20	0.19	0.19	0.20	0.21	0.21	0.21	0.21	0.21	0.19	0.19	0.20	0.20	0.19	0.19	
R2	Mean Profile Depth (Avg)	0.50	0.50	0.50	0.50	0.71	0.54	0.50	0.51	0.49	0.50	0.51	0.50	0.55	0.54	0.55	0.54	0.54	0.54	0.53
	% Dropouts (Avg)	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	
	RMS (Avg)	0.28	0.28	0.28	0.27	0.33	0.29	0.25	0.25	0.25	0.25	0.26	0.25	0.30	0.29	0.30	0.30	0.30	0.30	
R3	Mean Profile Depth (Avg)	0.07	0.07	0.07	0.07	0.07	0.07	0.11	0.11	0.11	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.10	0.10	0.09
	% Dropouts (Avg)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	RMS (Avg)	0.04	0.04	0.04	0.04	0.04	0.04	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.05	0.05	

*The Control sections were the last 3 slabs on the left before the beginning of the transition before section L1.

Table IV – HydroTimer drainage time data

SAMPLE NO.	TEST SURFACES; TIME, SEC						
	L0	L1	L2	L3	R1	R2	R3
1	14.21	12.06	2.84	11.23	12.91	9.65	6000
2	11.89	10.53	2.64	9.14	12.28	9.83	"
3	13.28	8.86	3.44	11.37	14.05	13.85	"
Average	13.13	10.48	2.97	10.58	13.08	11.11	6000*

*Very, very smooth

Table V - IFI Constants

GripTester	A	B
GT300 40mph	0.1173	0.4580
GT448 40mph	0.1249	0.4427
GT225 40mph	0.1379	0.4578
GT557 40mph	0.1274	0.4392
GT343 40mph	0.1232	0.4081
GT344 40mph	0.1251	0.3868
GT226 40mph	0.1251	0.4040

FIGURES 1 - 16

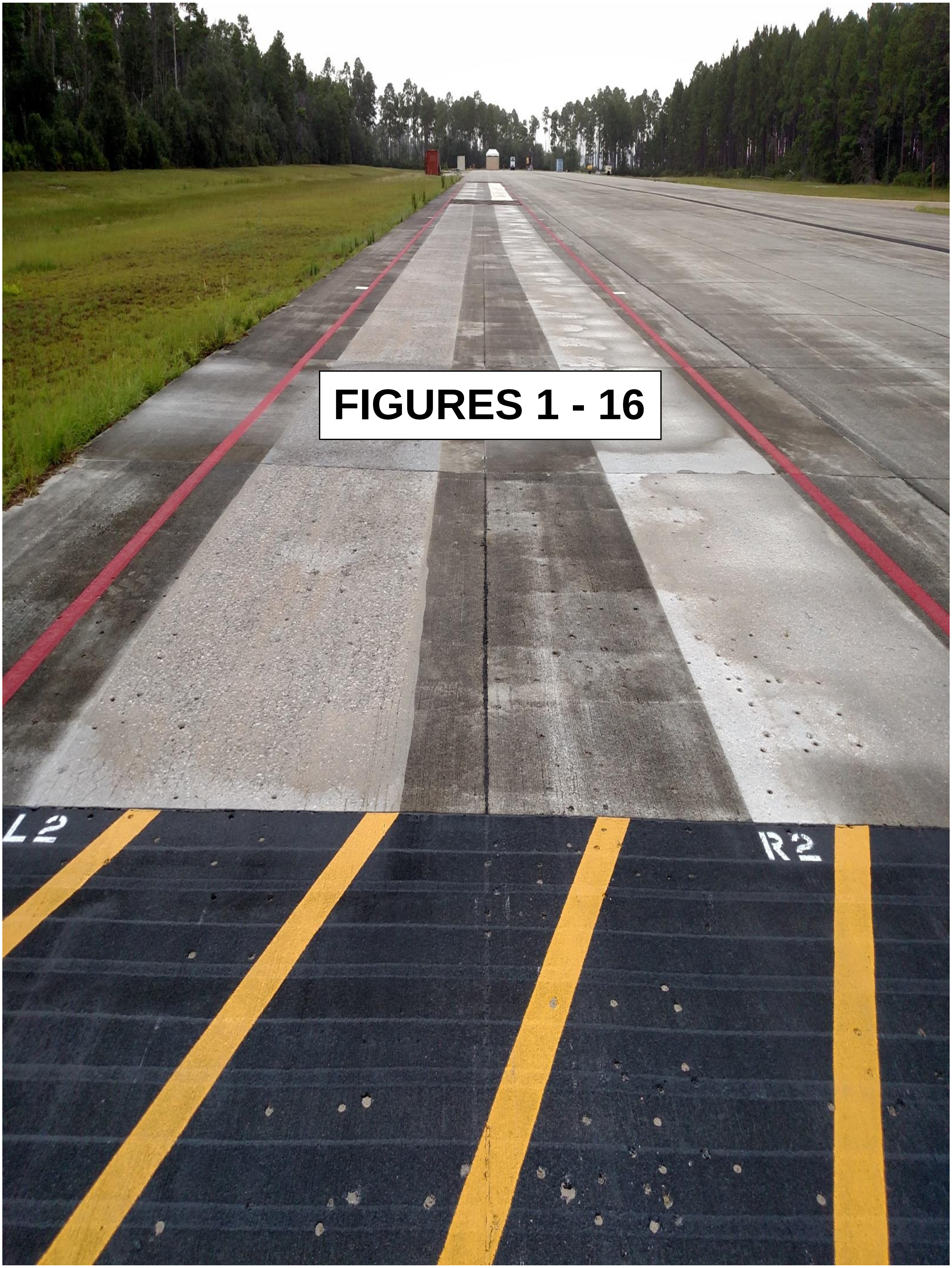


Figure 1.
Skidabrader High Velocity Shot Impact Machine

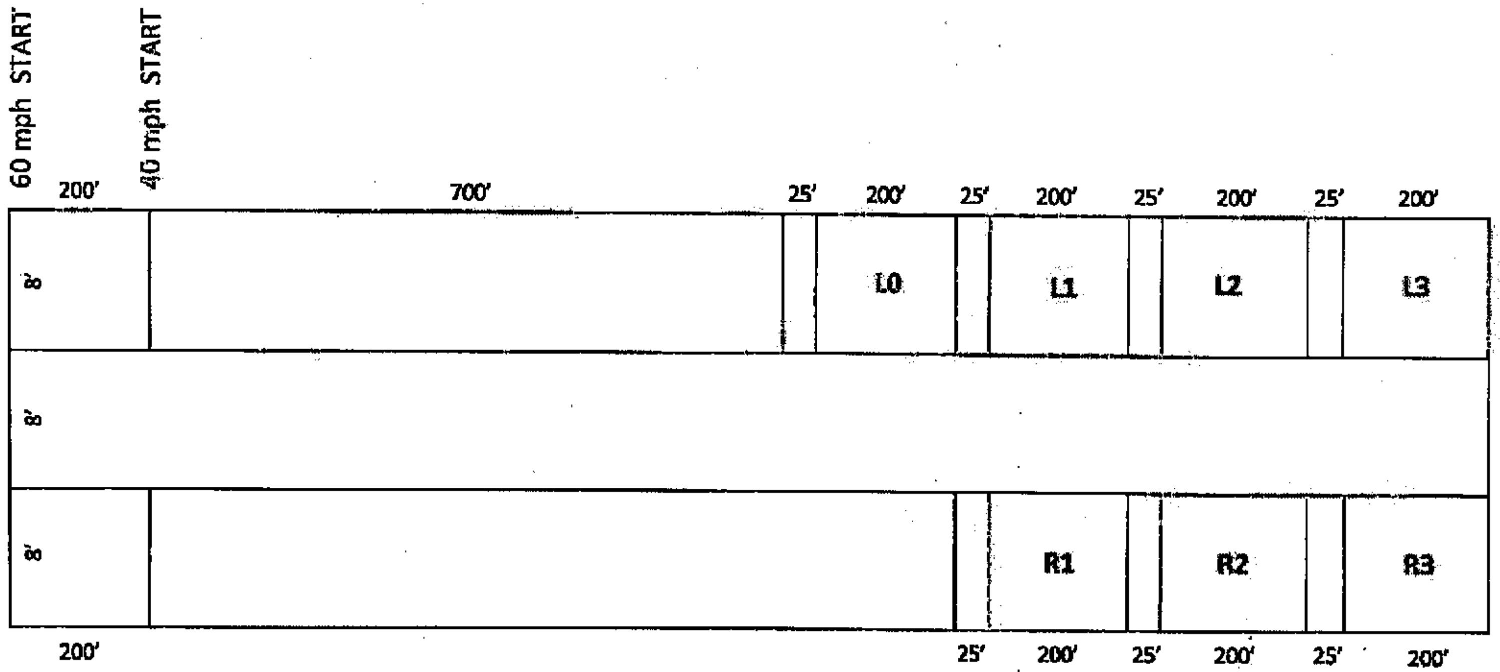
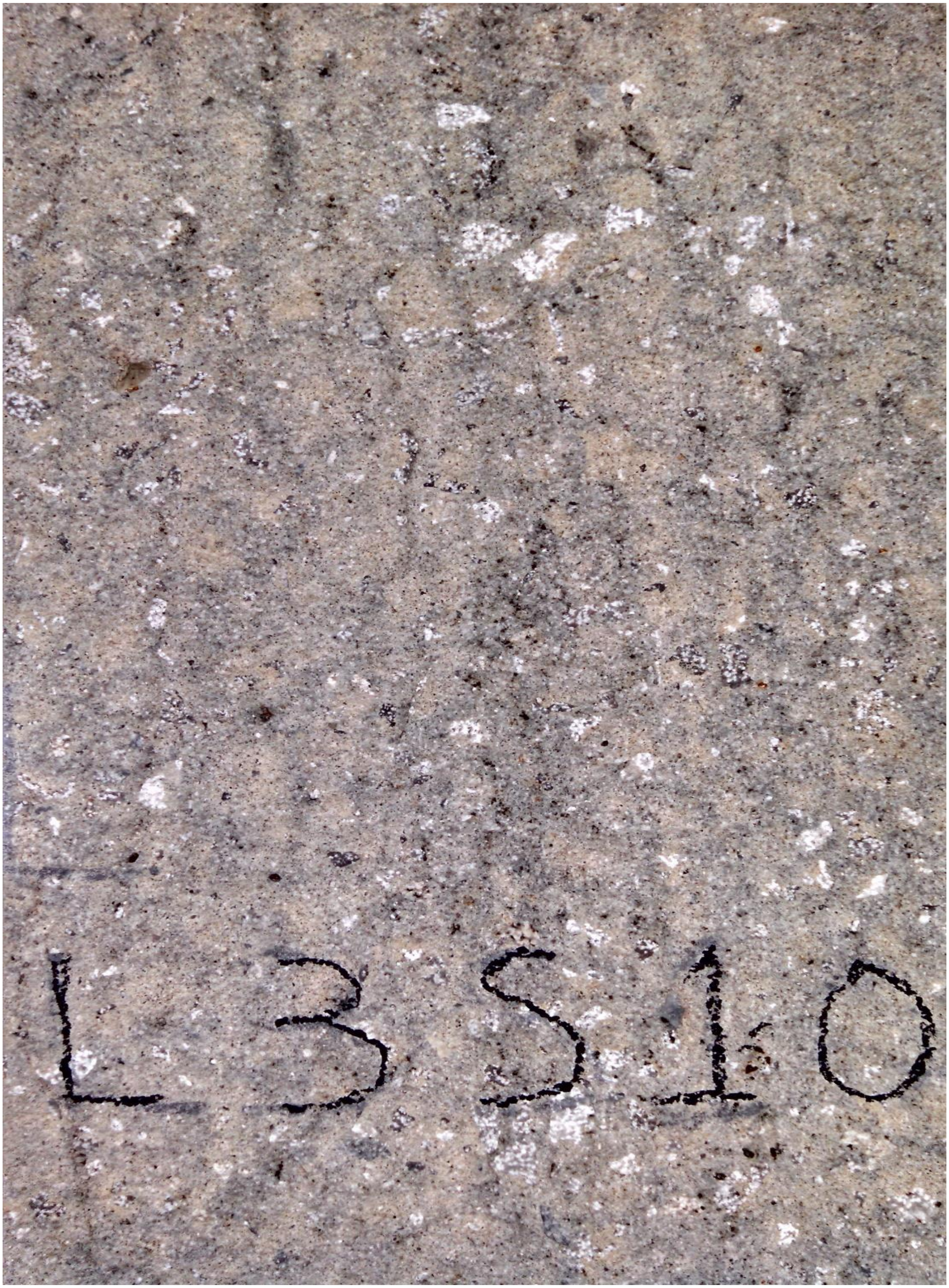
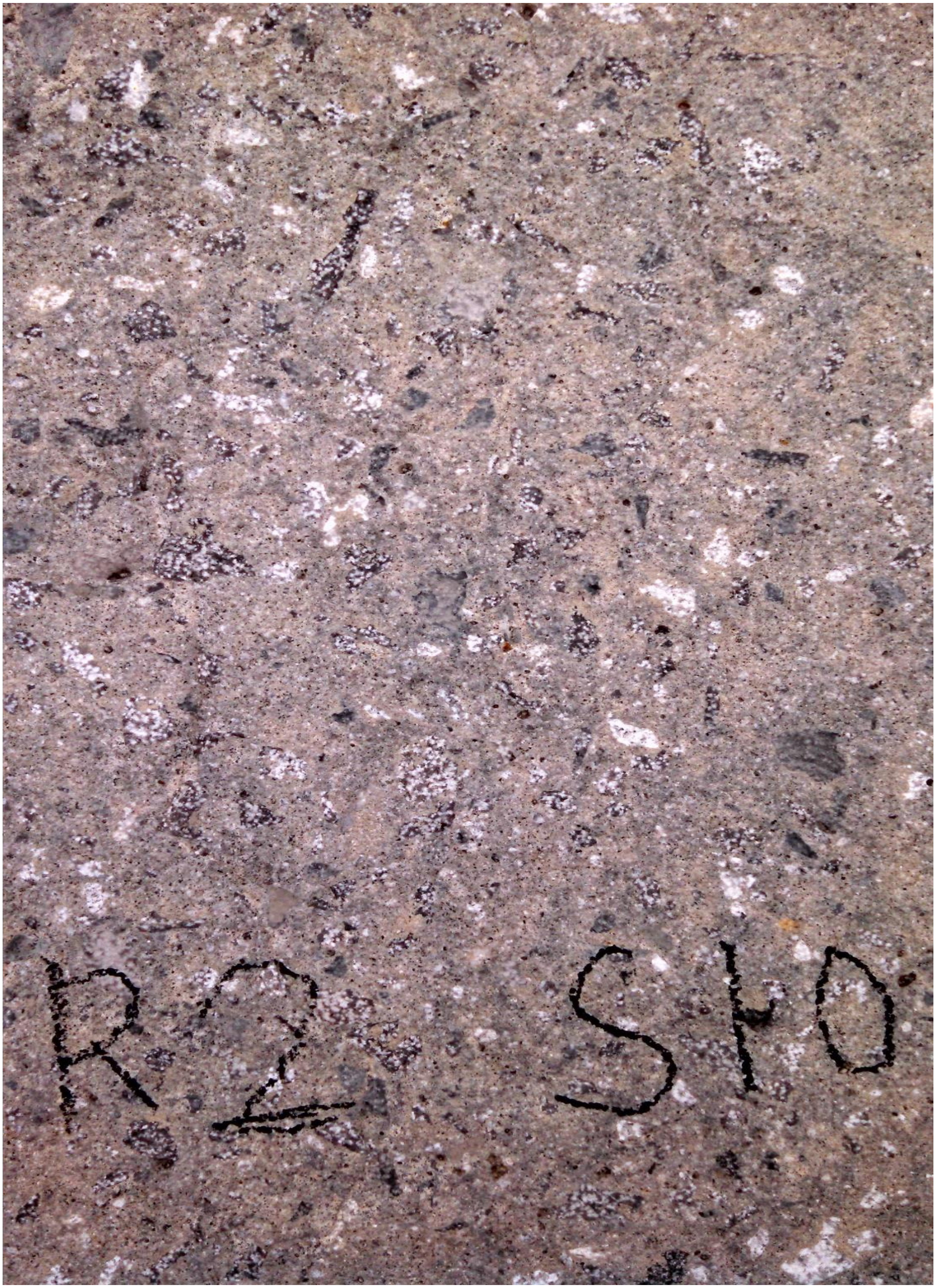


Figure 2. Schematic view of Tyndall AFB, Florida calibration site concrete surfaces


L1 S10


L2 S10


L3S10


R2 S10

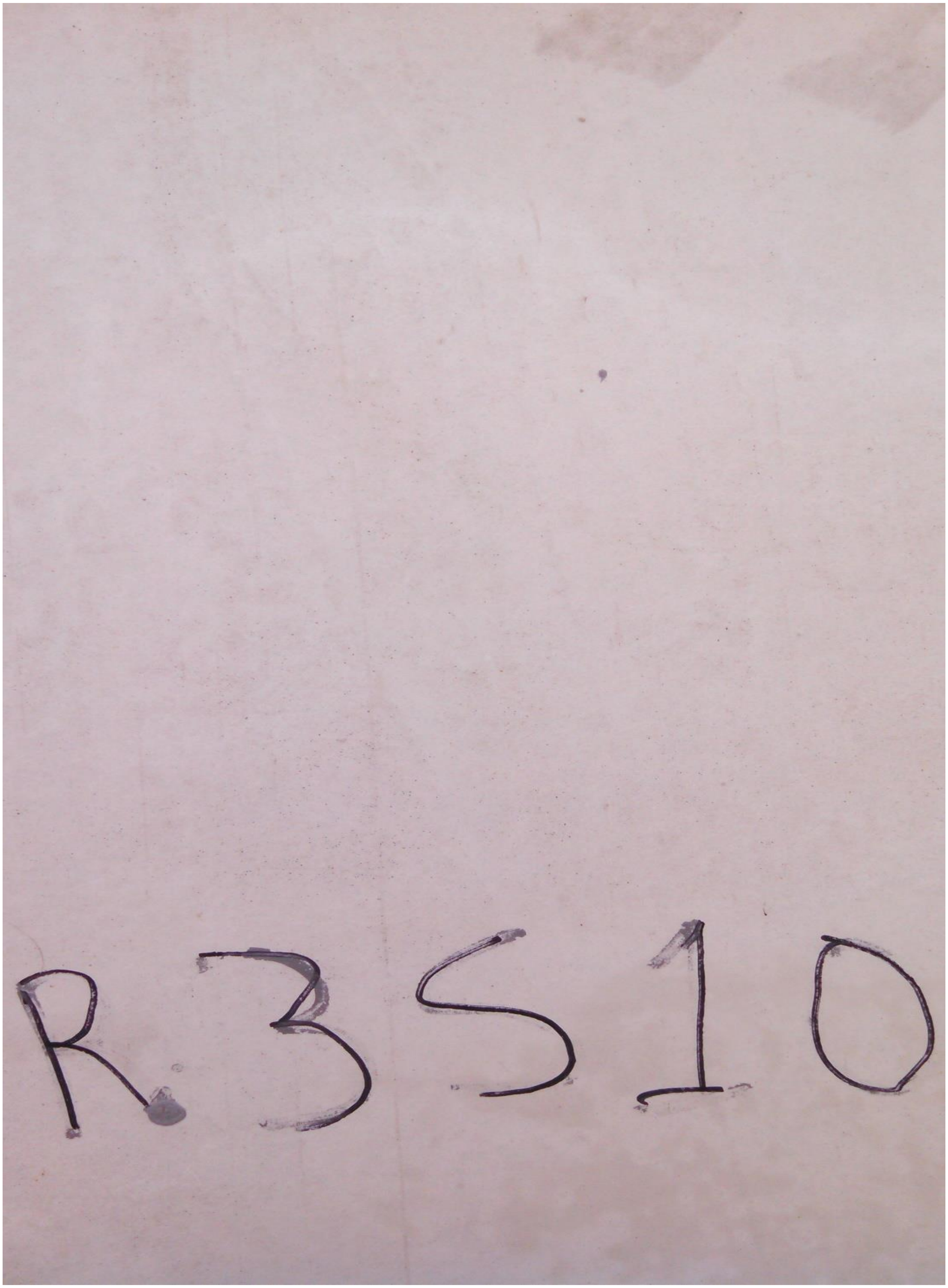

R3S10

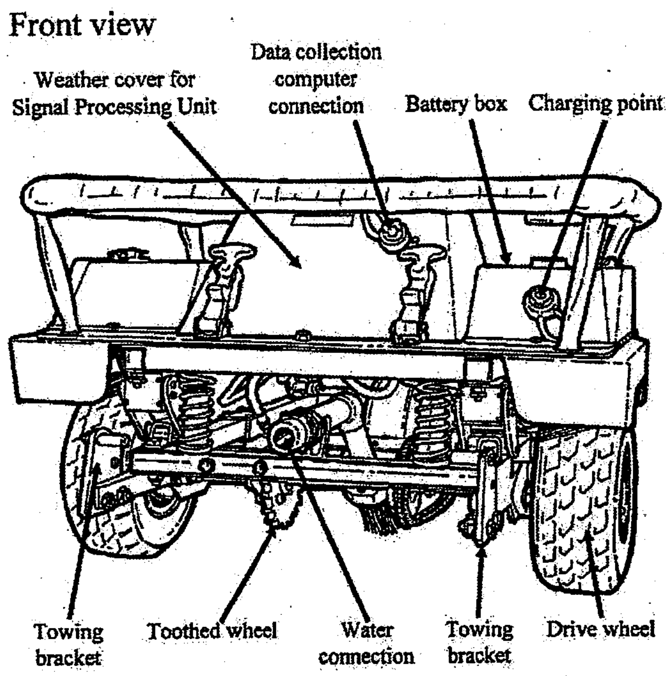
Figure 3.1.

Texture Depth Increased Using 40,000 psi High Pressure Water Demolition

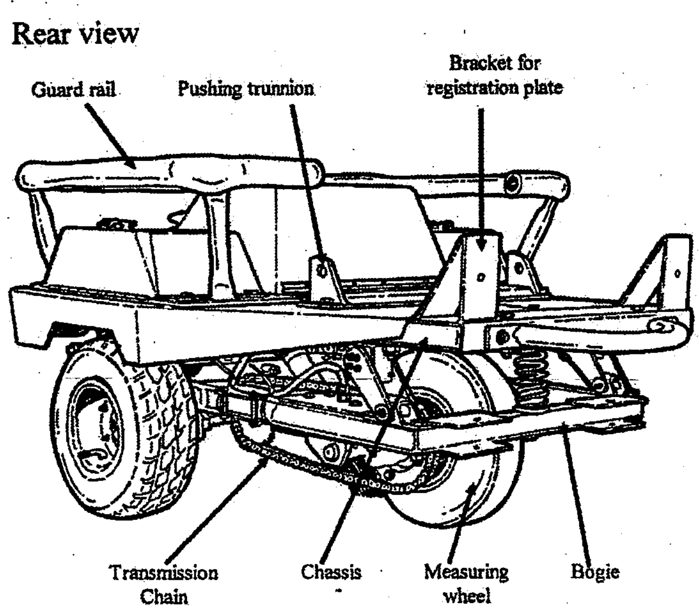
Figure 4.
GripTester Trailer

Figure 5.

MKI GripTester Underside Showing Test Tire, Chain Drive and Two Drive Tires



a. Front view



b. Rear view

Figure 6. GripTester schematic views

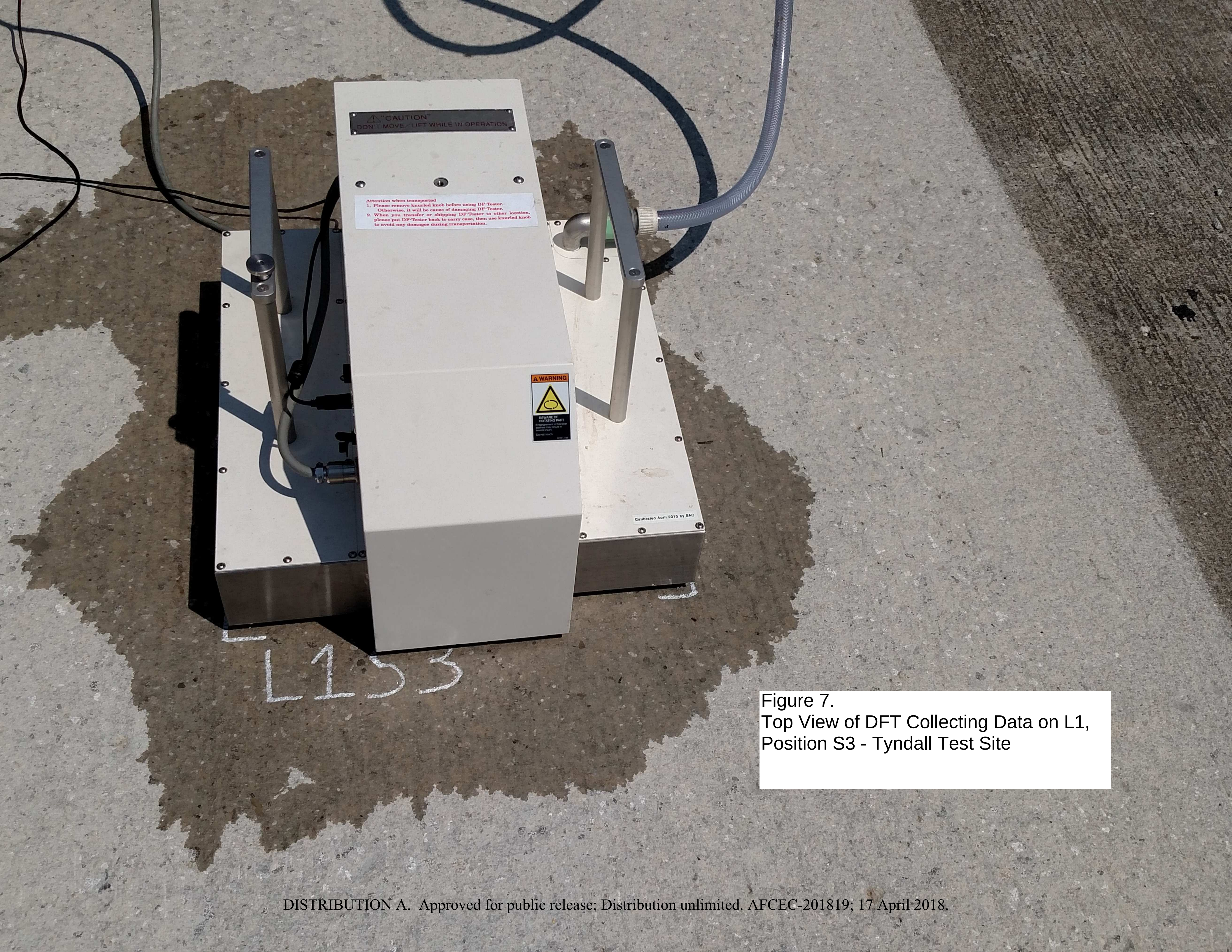


Figure 7.
Top View of DFT Collecting Data on L1, Position S3 - Tyndall Test Site

Figure 8

Bottom View of DFT showing Three Rubber Pad Mounted Arms

Figure 9.
CT Meter with Operator Collecting Data at Tyndall Test Site

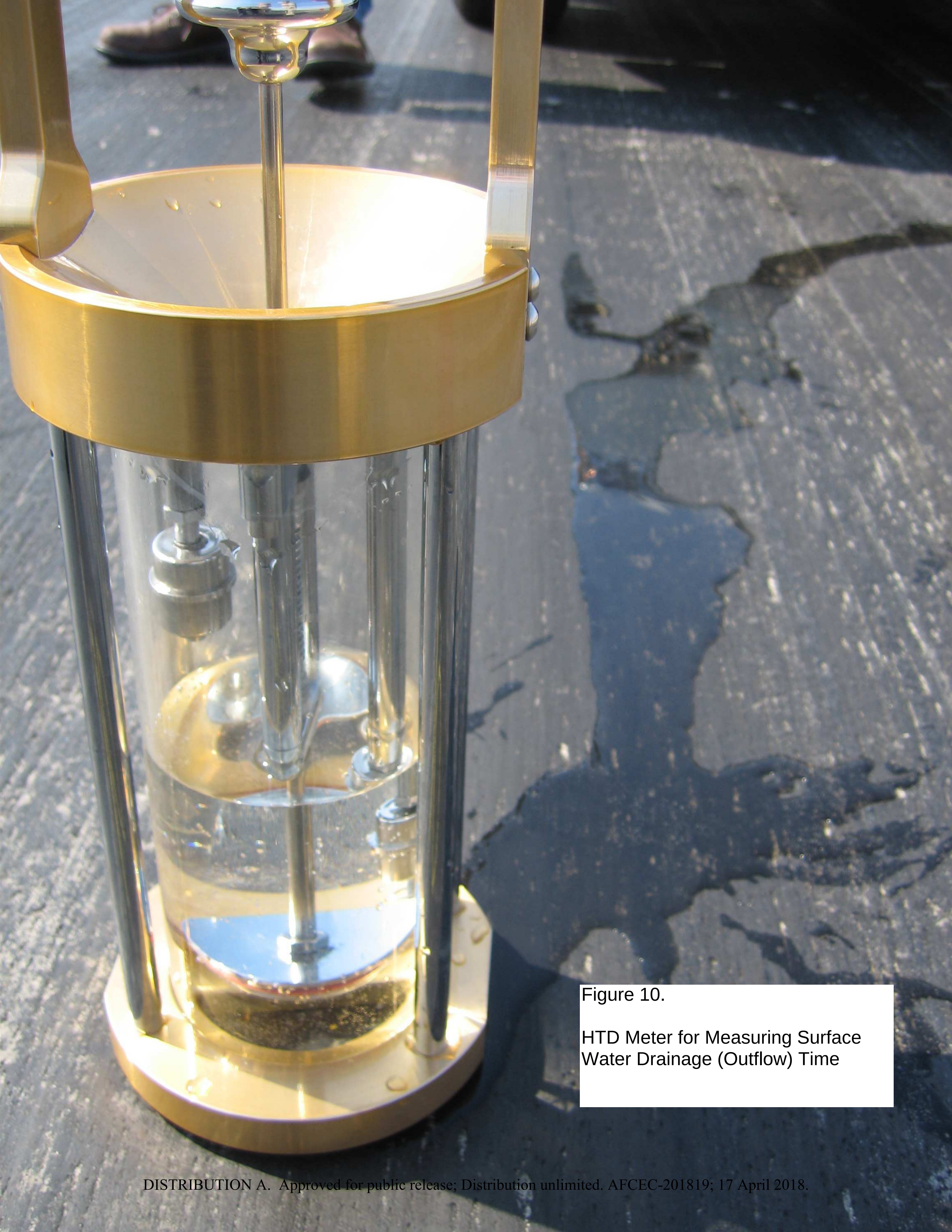
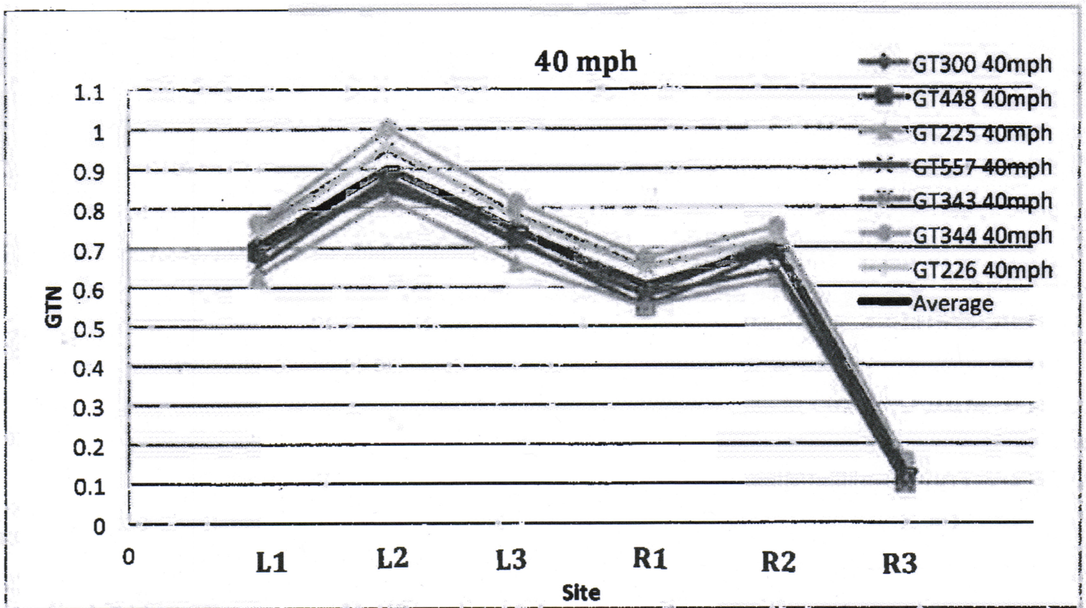


Figure 10.

HTD Meter for Measuring Surface Water Drainage (Outflow) Time



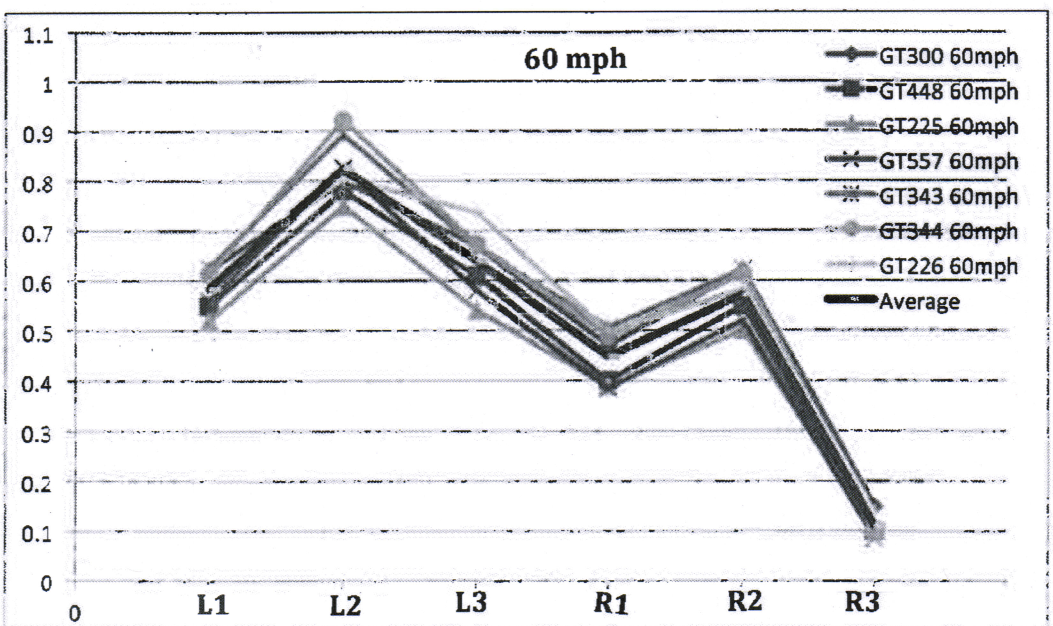


Figure 11. Plots of seven GT data at two speeds on each test surface

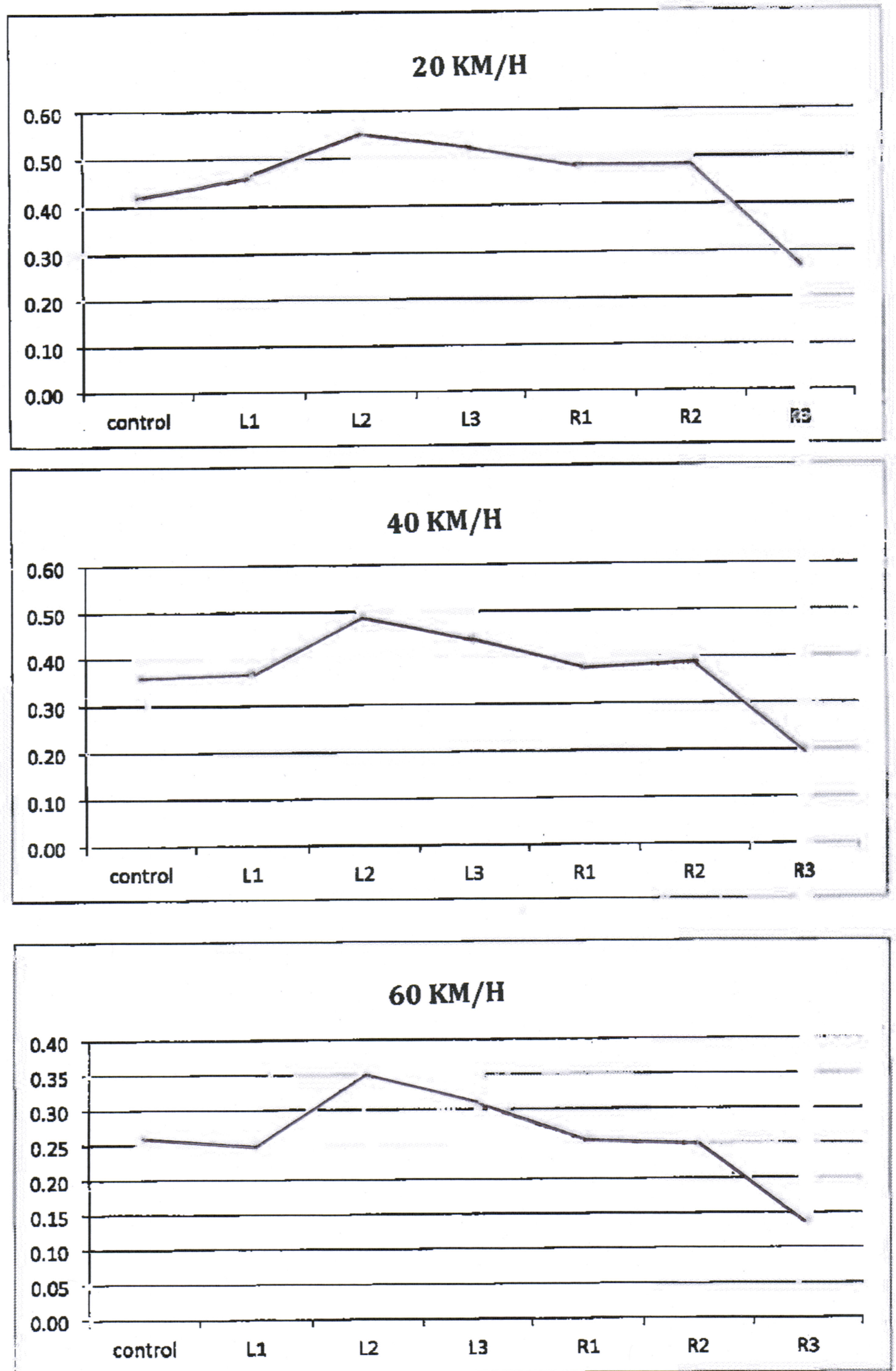
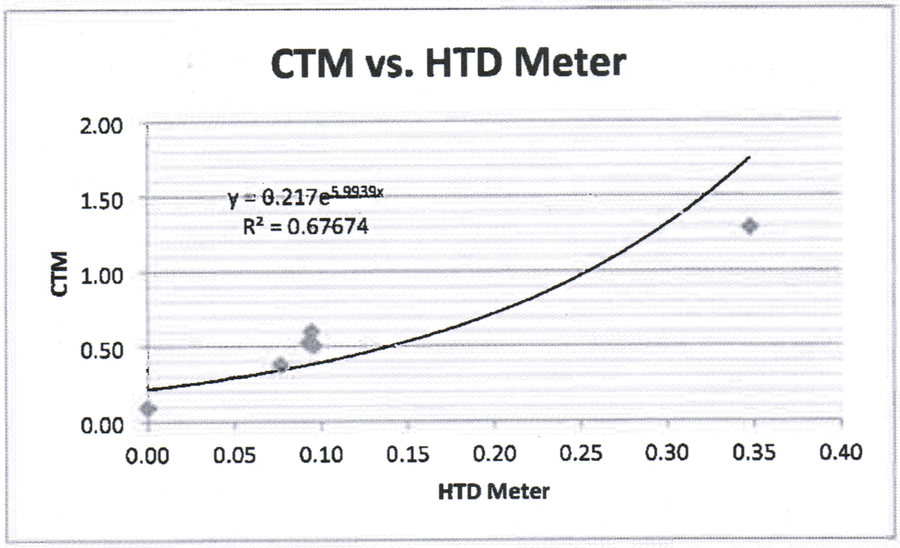
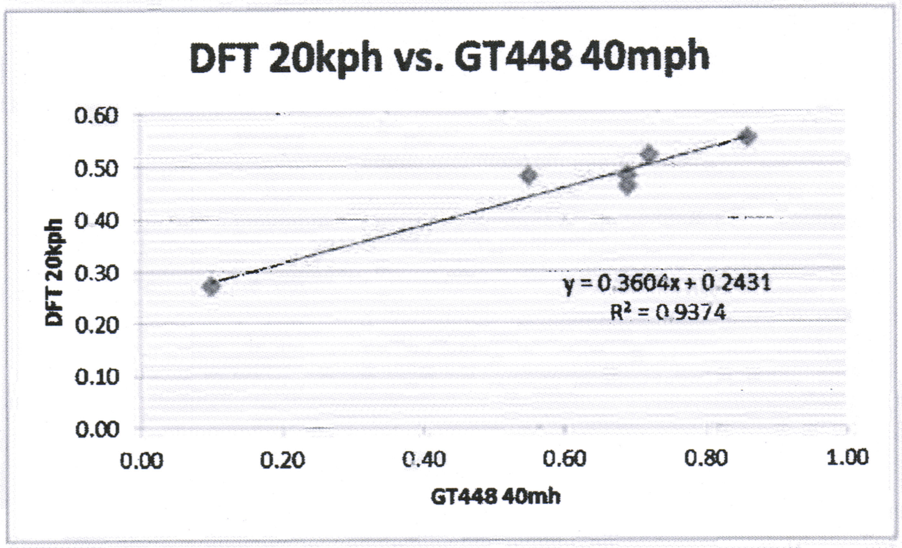


Figure 12. Plot of DFT data at three speeds on each test surface

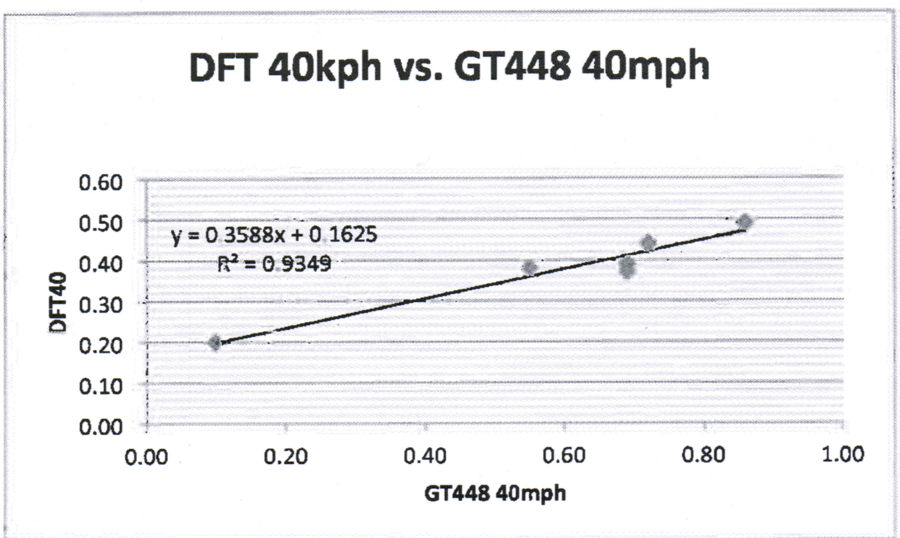


HTD Meter 1/sec	CTM MPD
0.10	0.51
0.35	1.29
0.09	0.60
0.08	0.38
0.09	0.53
0.00	0.09

Figure 13. Correlation plot between CT Meter and HTD Meter for each test surface

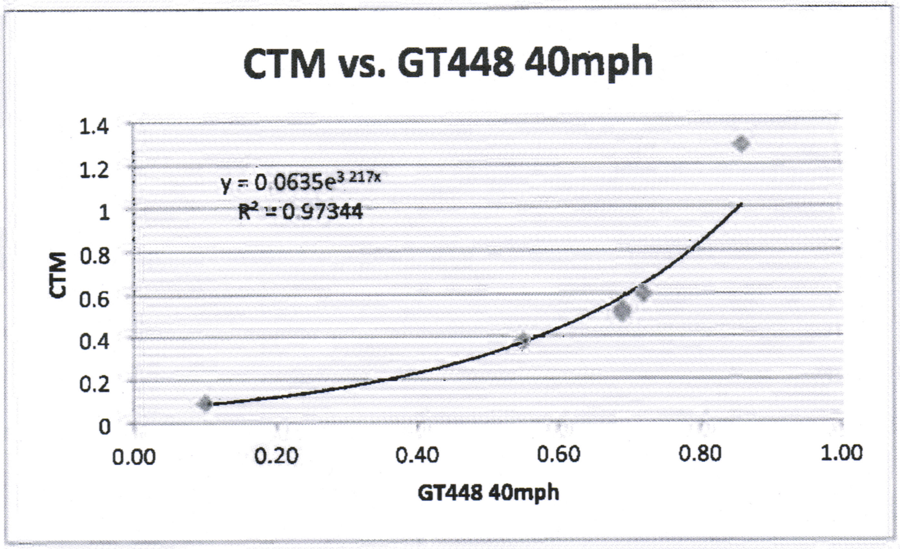


GT448 40mph	DFT 20kph
0.69	0.46
0.86	0.55
0.72	0.52
0.55	0.48
0.69	0.48
0.10	0.27



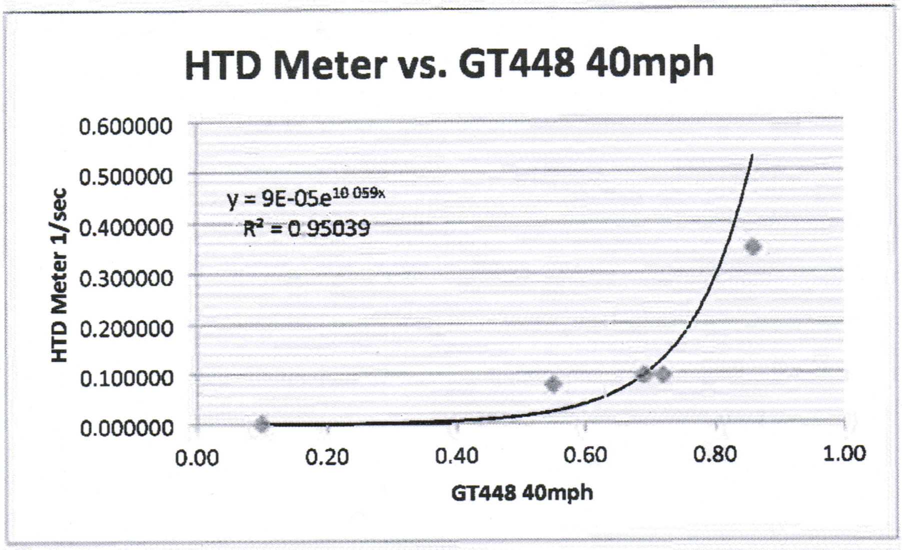
GT448 40mph	DFT 40kph
0.69	0.37
0.86	0.49
0.72	0.44
0.55	0.38
0.69	0.39
0.10	0.20

Figure 14. Correlation plot between golden GT448 and DFT for each surface and two speeds



GT448 40mph	CTM MPD
0.69	0.506667
0.86	1.286667
0.72	0.600000
0.55	0.376667
0.69	0.526667
0.10	0.093333

Figure 15. Correlation plot between golden GT448 and CT Meter for each test surface



GT448 40mph	HTD Meter 1/sec
0.69	0.095390
0.86	0.348028
0.72	0.094369
0.55	0.076453
0.69	0.092793
0.10	0.000167

Figure 16. Correlation plot between golden GT448 and HTD Meter for each surface